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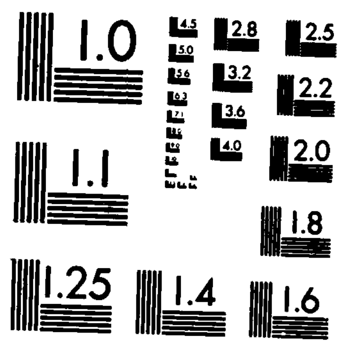
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In a continuing study of body heat loss in diving, seven series of experiments were done under an earlier contract (N00014-72-C-0057). Under the present contract, three ~~more~~ experimental series were completed: (VIII) Comparison of rest and work during fast and slow cooling in a suit calorimeter; (IX) Long slow cooling with performance testing; and (X) Body segment heat loss and gain determined by a segmental suit calorimeter and by heat flux transducers.

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Webb Associates

A STUDY OF BODY HEAT LOSS IN DIVING -- II.

Final Report, Contract N00014-80-C-0193

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March 15, 1983

Webb Associates

A STUDY OF BODY HEAT LOSS IN DIVING -- II.

Final Report, Contract N00014-80-C-0193

Contract N00014-80-C-0193 called for continuation of the work on body heat loss in diving that began in 1971 and ran through 1979 under Contract N00014-72-C-0057. During that period a total of 102 experiments involving 29 male subjects was performed, in seven different experimental series. All those experiments were central to the theme of relating physiological changes to body heat loss as encountered by divers in cold water. The first series involved crude calorimetric rewarming following direct exposure of swimming subjects to water temperatures of 5, 10, and 15°C. The second series involved nude men in an air environment in an environmental chamber. From the third series onwards, we used our suit calorimeter to simulate cold water exposure. One series was done in the bath calorimeter (nude exposures) at the Defence and Civil Institute of Environmental Medicine in Downsview, Ontario, Canada, in cooperation with Dr. Lorne Kuehn. We also studied weight loss in hyperbaric environments at the Universities of Pennsylvania and Hawaii, with Dr. Charles Puglia and Dr. Suk-Ki Hong, respectively. The experiments in Hawaii included continuous measurement of metabolism using equipment developed at Webb Associates, as well as estimates of energy balance.

Our objective throughout all these series was to learn more about the physiological nature of hypothermia induction from a thermal and metabolic viewpoint. Another goal was to create a biothermal model to unify the data obtained, with the hope that it would eventually be able to predict thermal responses of men in conditions that had not yet been studied experimentally. Our final series of experiments was for the purpose of model verification; nude men were exposed to cold water, head under, and the body heat loss data were compared with the predictions of the model.

The suit calorimeter referred to above was an adaptation of a liquid conditioning garment (LCG) similar to those worn by astronauts. It enabled us to study body heat loss without actually submerging a subject in cold water or exposing him to cold air. By measuring the change in temperature of the water across the LCG (from inlet to outlet) and the flow rate of the water through the suit, we could calculate the amount of heat lost by the subject's body; this was direct calorimetry. In conjunction with the LCG we used our metabolic measuring equipment, which accurately and continuously measured oxygen consumption and CO_2 production, thus furnishing a simultaneous measure of body heat loss (indirect calorimetry). The difference between body heat production, or metabolism, and direct heat loss as measured by the suit calorimeter was net heat loss.

During the period of the present contract, January 1980 through December 1982, we not only increased the accuracy and automation of the suit calorimeter, we also applied its principles to an LCG that was made in segments, so that heat exchange could be studied simultaneously from each of six compartments of the body:

head, torso, right and left arms, right and left legs. In effect, we were using six calorimeters at once. We developed the segmental suit in order to study the interrelationship of heat loss energetics and vasomotor effects on the various body segments, individually and simultaneously, using calorimetric techniques; we also felt that the segmental suit studies would help us to expand the model.

Dr. Philip Layton of the Naval Medical Research Institute was interested in the segmental suit work because he had been developing a heat flux transducer system for estimating the flow of heat from various parts of the body; he wanted to compare results obtained with the heat flux transducers to those obtained by our calorimeter. Cooperative experiments were arranged, and they were performed at the Webb Associates laboratory in 1981. From the standpoint of our own interests, the most valuable part of the segmental suit experiments was to try to partition total body heat loss so that we could compare heat lost from the limbs, for instance, with that lost from the head or torso, under fixed conditions.

The purpose of another series of experiments done during this contract was to examine the effect of exercise on body heat loss during rapid suit cooling; these constituted experimental series VIII of our continuing study of body heat loss in diving. Almost all of our previous experiments had been done on resting subjects; we wanted now to look at the thermal-energetic effects of exercise on hypothermia production, and specifically on body core temperature change during exercise and recovery.

The third major series of experiments done under this contract was a study to identify cognitive performance changes brought about by long, slow cooling such as occurs in certain underwater operations. This series of experiments continued from 1981 into 1982.

We will now give brief descriptions of experimental series VIII (exercise experiments); IX (performance testing); and X (segmental suit work), and mention the publications or reports that have resulted from each.

Series VIII. Comparison of rest and work during rapid suit cooling

To test the hypothesis that exercise (work) might make a change in the amount of body heat lost by a diver during cold water activities, or the way in which it is lost, we did a series of twelve experiments on three men who worked while being cooled in the suit calorimeter. By varying the temperature of the water entering the suit (T_{wi}), we established two different cooling rates: a slow one ($T_{wi} = 20^{o}C$) and a fast one ($T_{wi} = 10^{o}C$). First we cooled the subject at one of the two rates while he was resting, and then that rate was applied again while the subject pedalled a bicycle ergometer at 50 watts. As usual, net heat deficits were determined from the difference between continuous direct and indirect calorimetry.

The basic protocol was very similar to that used in previous experiments. Each experiment consisted of three phases:

a. Equilibration period, about 60 minutes, to stabilize subject and restore his quiet state after the activity of dressing.

b. Cooling period, fast or slow, for 60 to 120 minutes; subject seated at rest or pedalling a bicycle ergometer at 50 watts.

c. Rewarm, 60 to 90 minutes; subject seated at rest; heat lost through cooling is replaced by circulating warm water through the suit calorimeter.

In addition to the calorimetric measurements, skin temperature (T_{sk}), rectal temperature(T_{re}), and heart rate (HR) were monitored throughout each experiment. Analysis of the experiments included calculation of the cumulative energy balance each 10 minutes throughout the experiments; however, we were mainly interested in comparing ΔT_{re} and net heat loss at work and at rest when equivalent cooling rates were used.

At the mild cooling rate, the <u>net</u> heat loss over 60 to 90 minutes averaged 184 kcal when the subjects rested and 135 kcal when they worked. The change in T_{re} averaged -0.8°C at the end of mild cooling at rest, but rectal temperature actually rose by 0.2°C at the end of the mild cooling plus exercise. The afterdrop in T_{re} during rewarm was -0.3°C at rest and -0.8°C following work.

When the strong cooling rate was used, the net heat loss averaged 270 kcal at rest over the same time period, yet the fall in T_{re} was actually less (-0.6°C) than it had been at the mild cooling rate. When the strong cooling rate was imposed on the working subjects, their net heat loss was approximately 200 kcal, but T_{re} increased nearly 0.7°C over the same time period.

The results indicate that changes in T_{re} are not simply related to levels of heat loss. During mild work, T_{re} may be maintained at pre-cooling levels or be increased, despite net heat losses approaching 300 kcal. As has been demonstrated in earlier experiments, individual T_{re} responses are more related to rates of cooling and physiological factors than to simple anthropomorphic factors such as surface area, percentage of body fat, etc. Some individuals appear to be able to defend the core temperature better than others. Factors such as age and physical fitness level may be related to these characteristics.

Core temperatures, including esophageal, auditory canal, and rectal, generally fall faster as the rate of net body heat loss increases. At a sufficiently mild net cooling rate, such as 1 kcal/min, core temperature may not decrease significantly during many hours of cooling, or the decrease may be disproportionate in relation to the level of body heat loss. Changes in T_{re} of this type must be differentiated from normal circadian variation. The most responsive core temperature is the esophageal, next the auditory canal, and slowest of all to respond is the rectal, probably because it is thermally remote from the surface and from the central blood compartment. It has often been noted that rectal temperature has two curious responses: an initial rise after cooling begins, and an afterdrop when cooling has stopped and rewarming begins. Our experiments showed that the paradoxical rise in rectal temperature is accentuated and prolonged if the subject is working; indeed, rectal temperature may actually increase throughout the cooling process, and afterdrop may also be accentuated.

Our experiments made it clear that work alters both net body heat loss and the physiological consequences of cooling. However, to define this thoroughly would require a much larger and more varied series of experiments than we were able to do.

Two reports including different aspects of this work were presented at the 1981 annual meeting of the Undersea Medical Society in Asilomar, California, under the titles "Core Temperatures during Cooling," and "Core Temperature Changes during Cooling at Rest and Working."

Series IX. Long slow cooling with performance testing

Field experience has suggested the possibility that underwater swimmers and divers who lose heat slowly over many hours, never feeling terribly cold or shivering, and having only 0.5 to 1.5°C drops in core temperature, nevertheless make errors in complex tasks, which could be caused by the mild hypothermia. Confounding factors could include fatigue, distraction from discomfort, thermal or otherwise, and circadian rhythm effects.

Before this contract began Webb Associates had explored many kinds of cooling and cooling rates; we had not, however, studied performance as such, and we wanted to do so. To this end we consulted with experimental psychologists, including Drs. Bachrach and Brady of NMRI, in order to settle on three performance tests to use with the long slow cooling situation.

The first test we chose was the self-paced, 5-choice reaction time test. We rebuilt an apparatus we had been using in another project, making the task more difficult by separating the panel of lights from the response board, and more challenging in that the subject had to speed up his responses in order to get higher scores. The second test chosen was a television game calling for good motor skill and hand-eye coordination (shooting

down airplanes), recommended by Cdr. Bob Kennedy in his PETER program. The third test was designed to measure reserve performance capacity by requiring the subject to carry out a primary and secondary task simultaneously. The primary task was a simulated car driving test (TV game); while performing that task, the subject was required to listen to 4-digit numbers and repeat them backwards (secondary task).

We trained three male subjects to perform these tasks. (One woman was also trained and did control studies, but she no longer worked at Webb Associates when it came time to do the cooling runs.) The three male subjects are described below:

	age in yrs	height in cm	weight in kg	% body fat
Subject A	26	183	80	16
Subject B	58	172	88	28
Subject C	49	181	69	14

All three subjects were physically active and in good health. They were trained on the three performance tasks twice daily for four weeks until plateau performance scores were reached; their proficiency was maintained with further training sessions. Then we did extensive control studies in the suit calorimeter to control for fatigue and circadian rhythm effects.

When we were ready to combine the performance tasks with long slow cooling, we used the suit calorimeter for two 8-hour experiments on each man. Each session started with 1 to 1.5 hours of control during which the subject was maintained in thermal comfort. Then cooling started and continued for 6.5 to 7 hours.

The rate of cooling was steady but mild; heat loss rates as measured by the calorimeter were between 0.25 and 0.43 kcal/min. The subjects felt cool but not cold; they did not shiver, but sometimes their metabolic rate rose enough (pre-shivering) that we would trim back the cooling. The performance tests were administered in 40-minute sessions at the ends of the firs third, fifth, and seventh hours.

Net heat losses averaged 134 kcal (range 98 to 166 kc in the 6.5 to 7 hours of cooling. Mean skin temperatures [illegible] in the first hour of cooling from a comfort value of 33°C to 30.5°C while rectal temperature fell more or less steadily by 0.6°C on average (range 0.2 to 0.9°C).

For the 5-choice reaction time test, scores and times remained at the same levels as during control runs through the first five hours of cooling, but after 6.5 to 7 hours of cooling, reaction time increased by an average of 0.1 second from a control level which had averaged 0.57 seconds -- an increase of 18%. During control, errors had averaged 12 in 342 responses during the three minutes of the test. After cooling, the average number of errors increased to 23. All three subjects showed the performance decrement in the last hour of cooling.

The test to measure reserve performance capacity with primary and secondary tasks produced equivocal results. All subjects maintained their scores in the primary driving task throughout the cooling, and two subjects, A and B, attempted just as many trials of the secondary task (repeating 4-digit numbers backwards). Subject A improved his error score in the

last hour of cooling, and B worsened a little, but these changes were within one standard deviation of each man's control mean score. By contrast, in the last hour of cooling subject C attempted 16 and 17 trials of the secondary task in two experiments, versus a mean of 21.9 trials $\pm$ 2.9 (SD) during control. He also made more errors, increasing from 1.1 $\pm$ 1.0 in control to 6 and 7 errors in the final hour of cooling in the two experiments. It might be worth noting that subject C had the least body fat of the three and therefore perhaps was more affected by the cold; however, he was not significantly more affected than either of the others in the 5-choice reaction test.

In the pursuit task (TV game requiring the shooting down of airplanes), all of the subjects maintained their control scores throughout the hours of cooling.

To summarize these experiments, long slow cooling was accompanied by a slowing of choice reaction time, increased numbers of decision errors, and, in one man, evidence of overloading in a twin task. On the basis of this limited sample, it appears that mild hypothermia, gradually incurred without discomfort, can impair cognitive and motor performance.

This work will be reported on in detail at the 8th Symposium on Underwater Physiology, to be held in St. Jovite, Quebec, in June 1983, under the title "Impaired performance from prolonged mild body cooling," and will be published in the summary volume of the symposium.

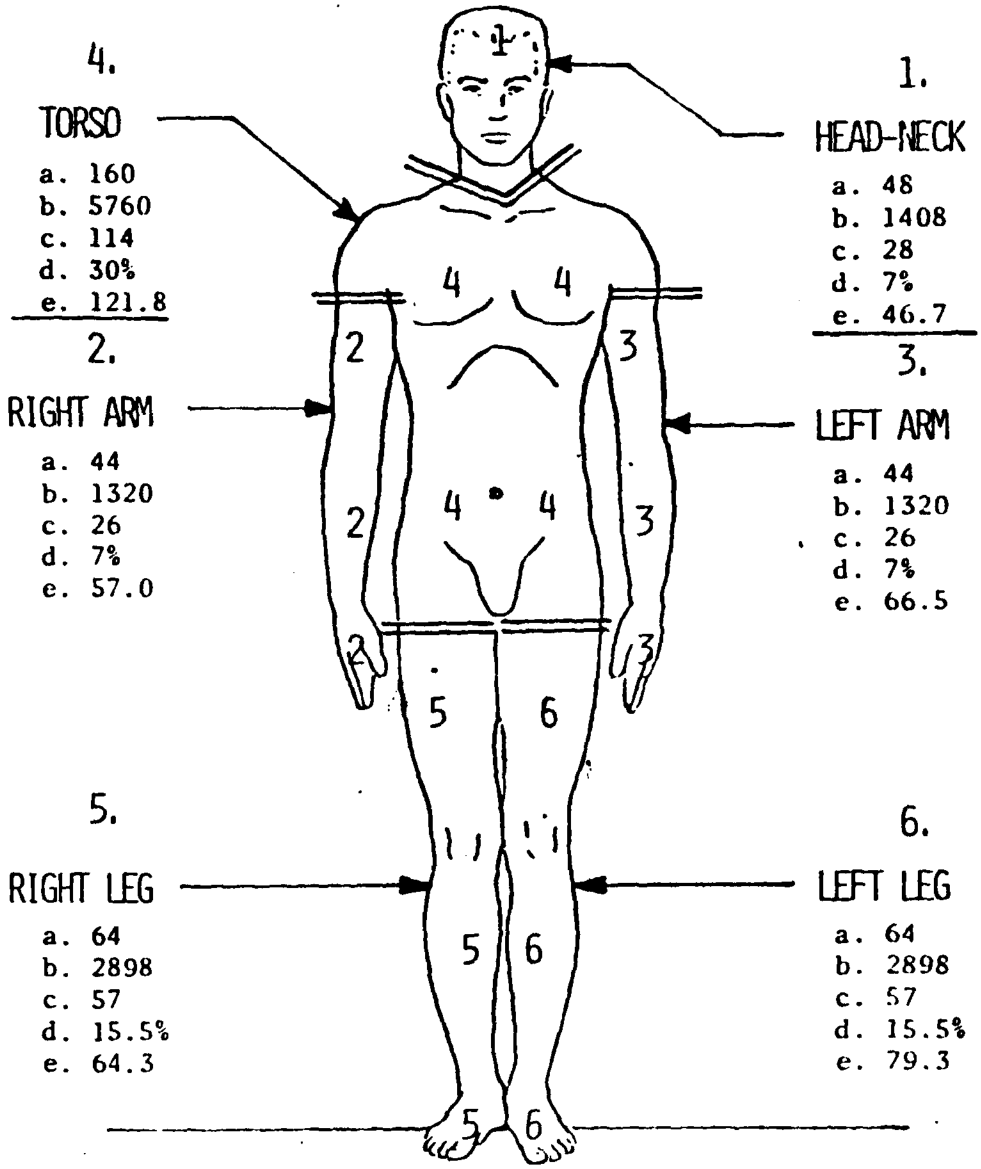
Series X. Body segment heat loss and gain; compartmentalized suit calorimeter system.

Our original suit calorimeter included a "low flow" suit. After finding that its cooling response time was not fast enough for what we wanted to accomplish, we created a "high flow" suit, which incorporated an increased density of water carrying tubes. This suit enabled us to cool (or rewarm) subjects at a much more rapid pace, and it gave excellent results. However, we wanted to study and compare the flow of heat from the various parts of the body, not just the body taken as a whole. In order to do this, we modified the design of the high flow suit so that instead of having a single water path from inlet to outlet it had six parallel paths, which isolated six body segments. Using this segmental suit calorimeter, we did a series of experiments in cooperation with NMRI as well as several using Webb Associates personnel only. Before describing the experiments and their results, we will give a brief description of the segmental suit system.

Segmental suit system

The segmented LCG was constructed of 584 small plastic tubes (0.16 cm ID, radially oriented on 1 cm centers), which were fixed to the inner surface of a nylon-spandex stretch garment. The compartmental scheme and some additional design engineering information are given in Figure 1. As usual, subjects wore a series of insulating garment layers over the water suit to reduce heat leak to known values when the environment was controlled to a constant 30^{o}C. In the suit as used in these experiments, each of the six compartments took its inlet water from a distribution network originating from a single main inlet manifold. The flow rate and the main inlet water temperature (T_{wi}) were automatically

Fig. 1 : The arrangement and anatomic limits of body segments in the six compartment suit calorimeter garment, including selected design information



LEGEND:

a. number of cooling tubes
b. length of tubes
c. volume of tubes small
d. approx. % of S.A. cooled
e. volume delivery & return + man

controlled and supplied by a water conditioning system. The six compartments were individualized by separation of the effluent water from each area. The outlet water temperature (T_{wos}) and flow rate ($\dot{m}_s$) of each compartment were individually measured. The segmental heat exchange via the water (Q_{ws}) was electronically computed and totalized using the relationship:

$$Q_{ws} = (T_{wi} - T_{wos})\ \dot{m}_s\ c_p$$ (where c_p is the specific heat of water)

In order to reduce measurement errors in Q_{ws} to a minimum, the T_{wos} thermistors were carefully matched to the single T_{wi} thermistor. Also, flow analog values of each segmental flowmeter were scaled against direct volumetric collections of effluent water (the full suit system likewise). Twenty thermistors were installed on the inner surface of the cooling garment for the measurement of skin temperatures. The six segmental Q_{ws} were manually recorded from the totalizer displays. These were sequenced on a 5 or 10 min time base to the main data system, which processed and printed all of the other data including the totalized $\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$, from which the metabolic heat production ($\dot{M}$) was calculated. The net heat lost or gained by the subjects -- energy balance (EB) -- was calculated each 5 or 10 mins of an experiment using the relationship: $M - \Sigma Q = EB$, where ΣQ is the sum of all heat exchanges.

Protocol

The protocol used with the segmental suit system essentially duplicated one often used in the past with single compartment suits. The experiment would start with a 60-minute equilibration period during which the water temperature (T_{wi}) was set to maintain comfort and produce a stable EB near zero (T_{wi} about 30°C). The equilibration period was followed by a cooling period during which T_{wi} could be lowered over about two minutes to a minimum of 3°C. The length

of the cooling period depended in large measure on the subject's responses and his ability to tolerate the cold. Generally we did not want the subjects to experience severe shivering, but at least 60 minutes of cooling at a given T_{wi} was the goal. Following the cooling period, the subject was rewarmed (sometimes initiated at his own request) by raising the T_{wi} over approximately 5 minutes to 35-40°C. Rewarming was continued until most heat lost during the cooling was replaced, or until the T_{re} afterdrop was past and T_{re} had started to increase. Usually 1 hour of rewarming was sufficien

Cooperative experiments

As mentioned above, Dr. Philip Layton of NMRI was interested in verifying the Navy's heat flux transducer system by conducting a series of experiments in which the subjects would wear the segmental suit calorimeter while they were also instrumented with the heat flux transducers. In the summer of 1981 Dr. Layton brought five Navy volunteer subjects to Yellow Springs in order to perform the experiments in the Webb Associates environmental chamber. A series of ten experiments was completed over a period of two weeks; each subject participated twice, undergoing a series of two or three cooling and warming cycles over approximately 6 hours. The procedure for the experiments is described below.

Fourteen heat flux sensors with integral thermistors were attached to the subject's skin with a medical adhesive. The sites selected were all along the left side of the subject's body. For comparison purposes, a 15th sensor was placed at a location on the right side; it was found that there was very good agreement between the data from each side. The heat flux transducers had all been previously calibrated using an instrument designed to measure thermal conductivity. Since it took a good deal of time to calibrate

each transducer individually, the process was not repeated before each experiment. Periodic checks were made, however, and showed that the calibration factors remained constant after repeated use. The thermistors and their associated circuits were calibrated directly before each experiment by placing the sensors first in an ice bath and then in a 40°C bath.

For safety purposes, a 3-lead electrocardiogram (ECG) was monitored, and to insure that core temperature remained above 35.5°C during the cooling phase, rectal temperature (T_{re}) was monitored using a linearized thermistor probe inserted 12 cm into the subject's rectum. During all experiments the environmental chamber was controlled to an air temperature of 30 ± 1°C; water vapor pressure of 15 ± 1 mm Hg; and a fixed air flow of 0.2 M/s.

Five U.S. Navy personnel volunteered as subjects for the project. They had given their informed consent, and the protocol had been approved by the Human Use Committee of the Naval Medical Research Institute and by the Institutional Review Board of Webb Associates. A description of the subjects is given below:

Subject	Age (yrs)	Height (cm)	Weight (kg)	Body surface* (M^2)	Skinfold thickness** (mm)
A	30	174.0	80.0	1.95	17.5
B	24	173.0	78.6	1.93	17.8
C	22	180.5	73.3	1.91	15.1
D	23	177.0	74.0	1.93	11.8
E	21	169.5	72.6	1.81	14.5
mean:	24	174.8	75.7	1.91	15.3

*computed from the formula of DuBois and DuBois (1).

**mean of six measurements (triceps, biceps, subscapular, suprailiac, abdomen, calf) with Lange skinfold calipers.

On the day of an experiment, the subject was instrumented with the heat flux transducers, then he donned a suit of thin cotton underwear to reduce the effect of sensor proximity to the cooling tubes of the calorimeter. Over the cotton underwear he put on the segmental suit calorimeter. The additional layers of insulating clothing were a two-piece cotton/polyester flannel sweat suit under a heavy goose down parka and pants. Cotton socks, wool socks, and down booties were worn on the feet, and down mittens covered the hands. The cooling tubes for the head were attached to the inside of a down hood, which was further insulated by the hood of the parka. The only part of the subject not covered by the insulating garments was the face, which was, however, covered by the lightweight, clear plastic face mask that formed part of the metabolic measuring system. The entire instrumenting and dressing procedure took about two hours.

When the procedure was completed, the subject entered the chamber and seated himself in the comfortable chair provided there, with his legs extended and feet resting on a hassock. At the start of each cooling period the calorimeter inlet water temperature was adjusted to a selected level and maintained there automatically for as long as desired. Different cooling rates were achieved by varying the inlet water temperature. At a T_{wi} of 28°C, heat loss approximately matched metabolic heat production and the subjects were thermally comfortable. To achieve cooling, T_{wi}'s of 23, 18, 10, and 5°C were used. Net heat losses never exceeded 200 kcal/hr. Subjects shivered during the coldest conditions, but rectal temperatures never fell to the safety limit of 35.5°C. Following the strongest cooling periods, subjects were rewarmed at a T_{wi} of 35°C for 1 hour, or less if they began to feel too warm.

In examining the data from these experiments, it was seen that the flow of heat from the subjects had reached a nearly steady state rate by 40 minutes from the start of each cooling period. Comparisons of the heat flow rates of the suit segments and those calculated via the segmental algorithms for the heat flux transducer system were derived during the last 20 minutes at each cooling level. The values for the left and right legs did not differ significantly, nor did those for the left and right arms; the two leg segments and the two arm segments were therefore combined, leaving a total of four instead of six body regions to be analyzed.

To calculate heat loss rates from the heat flux transducer data, the thermal response of the right side was assumed to be symmetric to that of the left. Comparison of the flux measured by the 15th transducer, placed at various locations on the right side, with that of its counterpart on the left, supported the symmetry assumption.

Regional and total heat fluxes for the transducer array data were calculated using three different formulae, each of which was based on the average weighting coefficients of Hardy and DuBois (2). These weighting coefficients, when combined with the estimation of segmental surface areas, constituted the basis of the algorithms mentioned above. Heat loss rate data for the four segments, from the heat flux transducers, were then plotted as a function of the calorimeter rate for the same segment. Linear regressions were performed; they showed that the two systems compared favorably in terms of the overall relationship of the heat flow at the different inlet water temperatures; the slopes of the curves were very similar. No statistically significant non-zero intercepts occurred for any of the body segments.

The poorest agreement between the two sets of data was found on the head, although the linear correlation was still quite high.

Some of the disagreement could have been caused by the placement of the transducers on the head close to the area of maximum cooling. Another factor was that in the neck area the tubes did not fit closely to the skin; this could have resulted in poor coupling between the garment and the skin in the vicinity of the transducers and could have been partially responsible for the reduced heat flux measured by the sensors in this area.

In the arms, also, the linear correlation of the two techniques was highly significant, but the array system measured a lower rate of heat flux than the calorimeter did. Thus for approximately 25% of the body surface (head and arms), the transducers measured significantly less heat loss than did the tube suit. For the remaining 75% of the body area (torso and legs), the two techniques agreed to within ± 11% for the two separate regions and to ± 2% for the combined segment. For the whole body, the transducer method yielded heat loss rates that were 87% of the suit calorimeter values.

Since all data in these experiments were taken from subjects during periods of steady state heat loss, the good agreement between the two methods cannot be assumed to be the same if rapidly changing heat fluxes were involved. But under the conditions of these experiments, the two methods did show a high degree of correlation, giving promise that heat flux transducers can become a reliable as well as convenient tool for use in diving physiology.

For a detailed report on these experiments, see Layton, R.P., et al., "Calorimetry with heat flux transducers: comparison with a suit calorimeter," Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology 54: (000-000), in press 1983.

Modification of segmental suit calorimeter and new work

After the cooperative study with NMRI, we used the segmental suit calorimeter to perform several experiments using Webb Associates personnel as subjects. It became clear to us that if we were to be able to quantify regional heat losses during cooling, we had to make the suit more truly segmental. As it was, with a single inlet water manifold and a single pump, there could be no adjustment of T_{wi} to different segments and only slight adjustment of flow within the segment.

The questions we wanted to explore in our future experiments were:

1. Is limitation of heat loss by vasoconstriction widespread over the body, or is vasoconstriction greatest on the arms and legs and not especially effective on the torso and head?

2. Does the concept of an expanding shell with constricting core during cooling fit with regional heat loss data? How much heat can be lost from the shell (at different cooling rates) before core temperature starts to drop significantly?

3. What do regional heat loss data suggest are the best areas to protect, and where should supplemental heat be applied?

4. After cooling is stopped, what areas most readily accept rewarming, and how does varying the regional application of heat affect core and central blood temperature?

To look at such questions required that the segmental suit be set up so that each of the six segments could be separately controlled for cooling rate, i.e. it had to have six water loops with controllable water temperature and flow in each. Also, it would

be necessary to improve our data handling system so that it would have the increased speed of measurement required for the far greater amount of data to be gathered.

We proceeded to isolate the suit's segments by equipping each one of them independently. We had already re-instrumented the main water control loop so that from the single inlet there arose separate outlets to give six outlet temperatures, and six outlet water flows. Now we built six entirely distinct water loops so that we could have varying inlet water temperatures and flows. Each loop consisted of: a pump, a heat sink, a heater with proportional temperature control, an inlet thermistor, an outlet thermistor, connecting tubing, accurate flowmeter, and a bubble trap. The inlet and outlet thermistor probes were located in newly designed fittings that lay inside the clothing assembly immediately adjacent to each segment. (Two heat sinks were used, one for each three segments.)

In the new experiments planned, each of the water loops would provide information of interest in periods as brief as one to five seconds. We did not know how fast vasoconstriction would come with a strong cold stimulus, but we felt that it should be in the order of five to ten seconds. Therefore the data system had to be able to handle 600 times as much data in each of the six water loops; this, however, would be no problem for a computer-based system. We had such a system, based on a Hewlett-Packard 9825 desktop computer and a Hewlett-Packard multiprogrammer and X-Y plotter. Since our other calorimetry projects were now finished, we were free to adapt the system to handle the masses of data from segmental suit experiments.

The task of instrumenting the six new water loops was exacting and time consuming; when it was finally finished we were ready to

calibrate the system. Calibration was accomplished by using an electrically heated dummy that had been modified to include independently controlled and heated segments to match the garment. A precision wattmeter was used to measure the heat supplied by the various segments. The calibrated suit and measurement system were then tested on one human subject prior to doing experimental work.

We used the improved segmental suit calorimeter to begin a study of vasomotor responses by segment, during comfort, cooling, and rewarming. Early data suggested that the combined mass of tubing and water was too great to allow any but the grossest vasomotor response (e.g. full vasoconstriction) to show up. Further exploration into vasomotor responses by segment should be done with special small heat flux sensors, which probably would have to be developed.

Other Activities of Contract N00014-80-C-0193

During the three years of the contract the Principal Investigator served as President of the Undersea Medical Society. He also participated in several workshops which concerned work being done under the contract.

One of the contract tasks was to organize a conference for the purpose of considering revisions of a document that had been produced earlier by Webb Associates, "Proposed thermal limits for divers: a guide for designers of thermally protective equipment." Under the auspices of the Naval Medical Research and Development Command, such a conference was held in Bethesda, Maryland in September, 1980.

This conference led to a report called "Physiological Design Goals for Thermal Protection of Divers," which was issued by NMRDC. The design goals set forth represented compromises between medical conservatism and freedom for the designer. NMRDC plans that these goals will be periodically revised and new guidelines issued as new evidence becomes available.

Immediately preceding the NMRDC conference, the Principal Investigator attended a workshop sponsored by the Undersea Medical Society on "Thermal Constraints in Diving" (also in Bethesda). He also took part in two other workshops pertaining to the work of the contract:

> "Thermal Stress in Relation to Diving." Sponsored by the Diving Medical Advisory Committee (Great Britain), and held at the Institute of Naval Medicine, Gosport, Hants., in March, 1981.

> "Workshop for the Evaluation of Thermal Models." Organized by Dr. Eugene Wissler, Dean of Graduate Studies, University of Texas at Austin, and held at the university in December of 1982.

During 1980 the Principal Investigator prepared a review entitled "Current Concepts of Metabolism and Thermophysiology" for the VIIth Symposium on Underwater Physiology, and traveled to Athens, Greece to present it. This was eventually published in Underwater Physiology VII (Undersea Medical Society). Another activity during the course of the contract was to revise a chapter on "Thermal Problems in Diving" for the standard text on underwater medicine (Bennett and Elliott; see attached publication list). The Principal Investigator has also interacted frequently with the engineers of the Naval Coastal Systems Center, Panama City, Florida, in their program on diver thermal protection.

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